

**INTERCONNECTED BROADCAST AND SELECT OPTICAL NETWORKS
WITH SHARED WAVELENGTHS**

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5 **CROSS-REFERENCE TO RELATED APPLICATIONS**

This application claims the priority of U.S. Provisional Application No. 60/309,220, filed July 31, 2001 and the benefit of U.S. Patent Application No. 09/575,811, filed May 22, 2000, which are both incorporated herein by reference.

BACKGROUND OF THE INVENTION

10 Field of the Invention:

The present invention relates generally to all optical networks, and more particularly to an all optical network that has a break point in a hub of a ring that becomes closed when a new break point is created in the network.

Description of the Related Art:

15 In today's long-haul dense-wavelength-division-multiplexed (DWDM) optical networks, multiple regenerators have been replaced by optical amplifiers. However, when interconnecting two or more metro ring networks, or when interconnecting a metro ring with long-haul systems, telecom operators are still relying on regenerators and O-E-O wavelength-converters. Wavelength-converters are needed because conventional DWDM
20 systems do not possess enough wavelengths to cover a wide service area such as multiple interconnected rings, and therefore wavelengths used in one ring must be re-used in another ring via wavelength converters. Regenerators are needed because most of the transmission technologies used in today's metro networks can only support limited transmission distance and data rates.

25 Conventional ring networks, illustrated in Figures 1(a) and 1(b) have a central hub which terminates all the wavelengths by a pair of DWDM mux and demux, an array of O-E-O regenerators, and an electronic cross-connect/switch, such as the one illustrated in

Figure 2. If the central hub in Figure 2 does not terminate all the wavelengths by DWDM mux/demux and O-E-O regenerators, there is a possibility that the wavelengths may circulate perpetually around the ring especially when excessive amplifications are supplied along the ring. This positive net gain can cause lasing phenomenon and consequently unstable received signals. A solution proposed in U.S. Patent 6,192,173 is that a controlled loss can be added to the ring, and the net round-trip loss should be large enough to prevent the onset of positive feedback but is sufficiently small to allow detection of optical signals to occur with a certain acceptable bit-error-rate. This method makes network control very complicated because adaptive loss control must be provided to different ring sizes and number of nodes, and the system bit-error-rate performance can be degraded.

In Figure 1(a), wavelength add-drop is carried out by using two optical circulators and a fiber Bragg grating (FBG). The FBG performs the "drop" function by reflecting a wavelength through the first optical circulator. Consequently, when there are two or more wavelengths needed to be dropped, more FBGs are inserted between the two optical circulators, and service disruption is incurred. In Figure 1(b), dynamic wavelength OADM is implemented in terms of wavelength separation and combination devices (e.g., a DWDM wavelength/band mux/demux pair), together with one or more optical switches—such as 2×2 or $N \times N$ devices.

For those wavelengths or bands that should pass through the particular node, the mux and demux pair are connected back-to-back, while for those wavelengths or bands to be dropped and added, there is a 2×2 switch inserted between the mux/demux pair. Depending on the predicted traffic per node, a system planner needs to pre-plan how many 2×2 switches must be placed in advance. This results in two problems, (1) once a fixed number of 2×2 switches are installed, future upgrade to install more switches can cause service disruptions, and (2) if an $N \times N$ switch is installed right at the beginning to cover every possible wavelength/band add-drop in the future, its cost will be high. In addition, the $N \times N$ switch long-term reliability is still questionable.

Despite the inflexible and non-scalable structure of the OADMs they do offer the wavelength reuse feature, i.e., the added wavelength can be the same as the dropped wavelength. This is a useful feature for ring networks with limited number of available wavelengths.

Another type of optical ring network, illustrated in Figures 3(a) and 3(b), uses optical couplers along the main path of the ring network to replace the complicated OADMs. This kind of optical network is a broadcast-and-select optical network, also referred to as a "one-hop" networks, which has been investigated in a DWDM all-optical star (R.

Ramaswami and K. N. Sirarajan, *Optical Networks: a practical perspective*, Morgan , 1998) and proposed in ring networks ("Flexible WDM network architecture", US patent 6,192,173, April 2001). A summary of a few variations of the arrangement of the two optical fiber couplers, booster optical amplifier, in-line or pre-amplifier, is shown in Figures 4(a) through 4(c).

In a broadcast-and-select architecture, whenever an optical transmitter launches a wavelength into the network, any user on the ring can receive this message (the "broadcast" characteristic of the network). A receiver receives its desired signal by using either a tunable filter or a fixed filter/demultiplexer (the "select" characteristics of the receiver). A tunable laser can also be used to launch a dynamically tunable wavelength into a fixed optical filter on the receiving end. In either case, the disadvantage is that no wavelength can be re-used. This is because the dropped wavelength will continue to propagate along the rest of the ring network(s), and no other nodes can use the dropped wavelength any more. Consequently, each transceiver card must receive at a specific wavelength, λ_x , and transmit at another wavelength, λ_y . This implies the broadcast-and-select network consumes wavelengths twice faster than DWDM networks using conventional OADMs. Most of today's metro-ring optical networks have a limited number of available wavelengths, consequently one cannot afford not to "re-use" the "dropped" wavelengths. Therefore, today's DWDM metro-ring optical network seldom uses broadcast-and-select scheme.

There is a need to provide an all optical network, and method, that eliminates all of the wavelength converters and regenerators between optical networks. There is a further need for an all optical network, and method, that eliminates all of the wavelength-dependent OADMs within an optical ring network. There is a further need to provide a large number of wavelengths available in an all optical network to facilitate the use of the broadcast-and-select all-optical fiber network architecture. There is a further need to design an all-optical protection scheme for this broadcast-and-select network which eliminates wavelength-dependent OADMs, regenerators, and any form of wavelength converters.

SUMMARY OF THE INVENTION

Accordingly, an object of the present invention is to provide an all optical network that eliminates all of the wavelength converters and regenerators between optical networks.

5 Another object of the present invention is to provide an all optical network that eliminates wavelength-dependent OADM's within an optical ring network.

A further object of the present invention is to provide a method for transmission in an optical network that uses a large number of wavelengths to eliminate the need for complicated OADM's, and to make the broadcast-and-select all-optical network
10 architecture practically usable.

Another object of the present invention is to provide a method that uses a large number of wavelengths that are transmitted over a long distance to cover multiple interconnected optical networks to eliminate all of the wavelength converters and regenerators between optical networks and all of the wavelength-dependent OADMs
15 within an optical ring network.

Another object of the present invention is to provide the combination of a dynamic wavelength-tunable optical transmitter and a dynamic wavelength-tunable receiver to simplify dynamic wavelength provisioning and configurability.

Yet another object of the present invention is to provide a method of transmitting
20 optical signal traffic in a multiple ring optical network by separating the optical signal traffic into ring bands, with the entire network transmitting all of the optical signal traffic and each ring receiving only its designated ring band.

Another object of the present invention is to provide a method of transmitting optical signal traffic in a hierarchical ring optical network by separating the optical signal traffic
25 into ring bands, with the entire network transmitting all of the optical signal traffic and each ring receiving only its designated ring band.

These and other objects of the present invention are achieved in a method of transmitting optical signal traffic. An all optical network is provided with at least two rings that are geographically dispersed. Each ring includes at least one transmitter and at
30 least one receiver. The available wavelengths are separated into distinct ring bands. The optical signal traffic is shared throughout the entire optical network. Each ring is provided with its own distinct ring band of the optical signal traffic. All of the optical signal traffic

is transmittable throughout the optical network. Each receiver is configured to receive only wavelengths in a ring band designated for its associated ring.

In another embodiment of the present invention, a method of transmitting optical traffic provides an all optical network with at least two rings that are geographically dispersed. Each ring includes at least one transmitter and at least one receiver. A large number of wavelengths are shared in the at least two rings without O-E-O conversions between the rings. The optical signal traffic is shared throughout the entire optical network. Each ring is provided with its own distinct ring band of the optical signal traffic. All of the optical signal traffic is transmittable throughout the optical network. Each receiver is configured to receive only wavelengths in a ring band designated for its associated ring.

In another embodiment of the present invention, a method of transmitting optical signal traffic provides an all optical network with hierarchical rings. Each hierarchical ring has a plurality of nodes and each node includes at least one transmitter and one receiver. The optical signal traffic is separated into ring bands. The optical signal traffic is transmitted through all of the hierarchical rings providing each hierarchical ring with its own distinct ring band. All of the available wavelengths are transmittable throughout each hierarchical ring. The receivers of a hierarchical ring are configured to receive only wavelengths in a ring band that is designated for that hierarchical ring.

In another embodiment of the present invention, an all optical network for optical signal traffic has at least a first and a second ring. Each ring has at least one transmitter and one receiver and its own distinct ring band of the optical signal traffic. All of the optical signal traffic is transmittable throughout the entire all optical network. Each receiver is configured to receive only wavelengths in a ring band designated for its associated ring. A central hub couples the at least first and second rings and separates the optical signal traffic into ring bands.

In another embodiment of the present invention, an all optical network includes a first ring with at least first and second protection fibers that carry all of the optical signal traffic. The optical signal traffic travels in a clockwise direction in the first protection fiber and in a counter-clockwise direction in the second protection fiber. At least one 1x1 or a 1X2 switch is coupled to each first and second protection fiber. The 1x1 or 1x2 switch is maintained in an open position when there is no break point in the ring and closed upon an occurrence of a break point in the ring.

In another embodiment of the present invention, a method of transmitting optical ring traffic provides a broadcast-and-select optical network. A sufficient number of wavelengths are transmitted over a long distance in the optical network to eliminate wavelength converters and regenerators between rings in a network.

5 **BRIEF DESCRIPTION OF THE DRAWINGS**

Figure 1(a) is a schematic diagram of the conventional OADM that is placed in the main path of the ring network for OADM using Bragg grating.

Figure 1(b) is a schematic diagram of the conventional OADM that is placed in the main path of the ring network for OADM using DWDM mux/demux and optical switches.

10 Figure 2 illustrates a conventional central hub consisting of DWDM mux/demux and electronic N×N switches.

Figure 3(a) is a schematic diagram of a broadcast-and-select or “one hop” optical ring network using only optical couplers at each node.

15 Figure 3(b) is similar to Figure 3(a), except that there are in-line amplifiers inserted between add and drop ports.

Figures 4(a) through (c) illustrate various arrangements of an in-line amplifier, booster amplifier and optical fiber couplers in each node along a ring network.

Figure 5(a) illustrates one embodiment of a wavelength-add-drop hierarchy.

Figure 5(b) illustrates another embodiment of a hierarchical wavelength add-drop.

20 Figure 6 is a diagram of a conventional SONET uni-directional protection switching ring (UPSR).

Figure 7 illustrates one embodiment of a two-fiber broadcast-and-select ring architecture of the present invention, with a pair of 1×1, or 1×2 switches in the central hub.

25 Figure 8 (a) illustrates operation of protection switches in the central hub and nodes of the Figure 7 embodiment when both fibers break.

Figure 8 (b) illustrates operation of protection switches in the central hub and nodes of the Figure 7 embodiment when a single fiber breaks.

Figure 8 (c) illustrates operation of protection switches in the central hub and nodes of the Figure 7 embodiment when a single optical amplifier fails.

30 Figure 9 illustrates operation of protection switches in the central hub and a node when a single optical amplifier fails.

Figures 10(a) through (e) illustrate an alternative protection ring design when using a

single optical fiber with east-bound traffic in one band, and west-bound traffic in another band.

Figure 11 illustrates that multiple rings can be interconnected in a manner such that they appear to be a single ring.

5 Figure 12 illustrates a central hub construction without O-E-O conversions for interconnecting two ring networks.

Figure 13 illustrates an out-of-band optical supervision/communication channel at 1510 nm for inter-nodal communication and protection switching.

10 Figure 14 illustrates a central hub construction without O-E-O conversions for interconnecting three ring networks.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

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15 In one embodiment of the present invention, methods are provided for transmitting optical signal traffic. An all optical network is utilized with at least two rings that are geographically dispersed. Each ring has at least one transmitter and receiver. A sufficiently large enough number of wavelengths is shared in both rings to achieve the sharing without O-E-O conversions between the rings. Alternatively, the available wavelengths are separated into distinct ring bands. The optical signal traffic is shared throughout the entire optical network. Each ring is provided with its own distinct ring band of the optical signal traffic. All of the optical signal traffic is transmittable
20 throughout the optical network. Each receiver is configured to receive only wavelengths in a ring band designated for its associated ring.

The present invention also provides all optical networks for optical signal traffic. In one embodiment the all optical network has at least first and second rings. Each ring has at least one transmitter and receiver and its own distinct ring band of the optical signal
25 traffic. All of the optical signal traffic is transmittable throughout the entire all optical network. Each receiver is configured to receive only wavelengths in a ring band designated for its associated ring. A central hub couples the first and second rings and separates the optical signal traffic into ring bands.

30 In another embodiment of the present invention, an all optical network includes a first ring with at least first and second protection fibers that carry all of the optical signal traffic. The optical signal traffic travels in a clockwise direction in the first protection fiber and in a counter-clockwise direction in the second protection fiber. At least one 1x1

or a 1X2 switch is coupled to each first and second protection fiber. The 1x1 or 1x2 switch is maintained in an open position when there is no break point in the ring and closed upon an occurrence of a break point in the ring.

With the methods and networks of the present invention, various arrangements of in-line amplifiers, booster amplifiers and optical fiber couplers in each node can be used, such as those illustrated by way of example and without limitation in Figures 4(a) through (c).

Figure 5(a) illustrates one example of a wavelength-add-drop hierarchy. As shown, along the main path of the ring network only broadband couplers, and possibly optical amplifiers, are used. On the addition side, an array of tunable lasers are added through an optical coupler. On the drop side, a fixed wavelength demultiplexer or an optical filters is located after a main-path coupler. Following the demultiplexer or optical filter an optional 1xM optical splitter and M tunable optical filters can be included. Each is utilized to extract a sub-wavelength channel.

Figure 5(b) illustrates another example of a hierarchical wavelength add-drop. As shown, along the main path of the ring network only broadband couplers, and possibly optical amplifiers, are used. On the addition side, an array of N fixed lasers are added through a DWDM multiplexer, for a large N, through a CDWM multiplexer or an optical coupler for a small N. On the drop side, a tunable wavelength OADM is located after the main-path coupler. Following the demultiplexer or optical filter is an optional 1xN optical splitter and N tunable optical filters. These extract a sub-wavelength channel.

Figure 6 is included to illustrate a conventional SONET uni-directional protection switching ring (UPSR) that can be used with the methods and networks of the present invention.

One embodiment of the present invention, illustrated in Figure 7, is an all optical network 10 with a first ring 12 that has at least first and second protection fibers 14 and 16 that carry all of the optical signal traffic of network 10. Optical signal traffic travels in a clockwise direction 18 in first protection fiber 14 and in a counter-clockwise direction 20 in second protection fiber 16. At least one 1x1 or 1x2 switch 22 is coupled to first and second protection fibers 14 and 16 in a central hub 24 or at any nodes 26 of network 10. Switch 22 is open under normal conditions and a break point is maintained in ring 12. A perpetual re-circulating of optical signal traffic is prevented. Each node includes one or more transmitters and receivers, mux/demux and fiber coupler. Every transmitter in

network 10 launches its signal in both first and second fibers 14 and 16. Because of the break point in central hub 24 only one of these duplicated signals can be received at a destination. The break point in central hub 24 also prevents the two duplicated signals arriving at the same destination in which case the two signals may be combined

5 destructively, they may be 180^0 out of phase.

When there is a broken fiber in network 10, as shown in Figure 8(a), a new break point is created. The old break point in hub 24 is immediately closed for both first and second protection fibers 14 and 16. Several other fiber or optical amplifier break conditions can also be protected by turning on and off the pair of 1×1 switches, as

10 illustrated in Figures 8 (b) through 8 (c). The embodiments of Figures 8(a) through (c) use the Figure 4(b) node configuration.

In Figure 8(a), both first and second fibers 14 and 16 are broken. In Figure 8(b), there is a failure in a single optical amplifier, and optical switch 26 is open to ensure that there is a break point in the clock-wise working ring. In Figure 8(c) a failure exists in one
15 optical amplifier. Optical switches 28 and 30 are switched in order to let launched signal bypass the failed in-line amplifier. Optical switch 32 is switched to open position to ensure that there is a break point in the clock-wise ring. In a normal operating condition, without a break or failure of a fiber or an amplifier, the transmitted signal arrives at the receiver in direction 18 or direction 20 but not in both. In Figure 8(a) through (c), the add
20 and drop arrangement is the same as illustrated in Figure 4(b).

In another embodiment of the present invention, illustrated in Figure 9 where the node structure follows that of Figure 4(c), only one switch 32 needs to be turned open to perform the same protection as that in Figure 8(c). In the Figure 9 embodiment, the add and drop arrangement is the same as that illustrated in Figure 4(c).

25 In other embodiments of the present invention, a single fiber 34 is used instead of dual fibers, as illustrated in Figures 10(a) through (e). In the Figure 10(a) through (e) embodiments each node has two optical amplifiers 36 and 38 arranged in such a condition that each one amplifies a band of optical signals and is oriented toward opposite directions. The same data is duplicated in the two bands 40 and 42 by using either two
30 optical transmitters 44 and 46, as shown in Figures 10(a), or by using a single transmitter 18 transmitting duplicated signals in different frequencies (wavelengths), as shown in Figure 10(d). The receiver in each node can select either of the two bands, which come

from different directions along the ring, by using a tunable filter which can tune from one band to the other.

When there is a fiber break or amplifier failure, the operation principle is the same as that of dual-fiber rings, as illustrated in Figures 10(b), (c), and (e). It will be appreciated that the preferred node structure in Figures 10(b), (c) and (e) follows that of Figure 4(c) instead of Figure 4(b).

Ring to ring interconnection can be achieved by breaking the rings and interconnecting them to form a single ring 50, as illustrated in Figure 11.

The Figure 11 embodiment forces each in-line amplifier in each node to amplify all wavelengths traveling along the ring, even though the wavelengths were not intended for that particular node. This can increase the cost of optical amplifiers.

In another embodiment of the present invention, illustrated in Figure 12, the wavelength loading on the in-line amplifier in each node is alleviated. In Figure 12, all optical network 52 for optical signal traffic includes at least first and second rings 54 and 56. Each ring 30 and 32 has at least one transmitter and one receiver and its own distinct ring band of the optical signal traffic. All of the optical signal traffic is transmittable throughout the entire all optical network 52. Each receiver is configured to receive only wavelengths in a ring band designated for its associated ring 54 and 56. A central hub couples first and second rings 54 and 56, and separates the optical signal traffic into the ring bands.

In Figure 12, some of the wavelengths can be sent to a second ring without going back to the originating ring. Thus the wavelength loading on each optical amplifier can be alleviated.

By way of illustration, in Figure 12 all the optical signal traffic is separated into two ring bands 53 and 55. Band 53 is for intra-ring traffic and band 55 is for hub or intra-ring traffic. Ring bands 53 and 55 can contain more than 200 wavelengths. Additionally, more than 200 wavelengths inside rings 54 and 56 can support both the wavelength-consuming broadcast-and-select architecture and long-term traffic growth. In Figure 12, band 55 travels inside one ring, while band 53 goes to the second ring. Each ring 54 and 56 includes at least one 1x1 or 1x2 hub switch 58 and 60, respectively. Switches 58 and 60 are controlled by a reserved out-of-band optical supervision channel (OSC). In one embodiment, the OSC is a 1510 nm channel. The OSC channel travels along the entire ring 54 and 56 hop-by-hop, as illustrated in Figure 13.

In Figure 13, two C-band/1510 nm couplers 62 and 64 are provided, one extracts the 1510 nm supervision signal from the ring and the other couples the 1510 nm supervision signal back to the ring. Consequently, 1510 nm supervision signals, which contain various control and management information, do not have to pass through an optical amplifier 66.

5 Because the out-of-band OSC channel monitors the operation status of both equipment and fiber in each ring node hop-by-hop, any fiber and/or amplifier break of network 52 can be immediately reported to a network manager based on the status of the OSC channel.

10 All or some of the ring bands can have the same or different numbers of optical signals. Preferably, none of the ring bands share common wavelengths and every wavelength in the optical signal traffic is in a ring band. First and second rings 54 and 56 can be geographically dispersed or hierarchical rings.

15 Rings 54 and 56 can be the same as ring 12 and include first and a second protection fibers 14 and 16, switch 22 and central hub 24, with the optical signal traffic traveling in clockwise direction 18 in first fiber 14 and in counter-clockwise direction 20 in second fiber 16. Again, in this embodiment, switch 22 is maintained in an open position when there is no break point in an associated ring, and is then closed when there is a break point in a ring.

20 An extension of Figure 12, for three ring interconnection, is illustrated in Figure 14. In Figure 14, network 52 has a third ring 58 and a central hub 60 does not have O-E-O conversions. In this embodiment, optical signal traffic is separated into bands 62, 64 and 66 that are separately assigned to each ring 54, 56 and 58. Central hub 60 includes a band-splitter that separates the wavelengths of the optical signal traffic originated within network 52. In central hub 60, the optical signal traffic heading for first ring 54 combines with the optical signal traffic originating from second and third rings 56 and 58 and merge back into first ring 54. A similar structure is used for a second fiber. As illustrated, 1x3 couplers are used in each ring 54, 56 and 58 to combine the same band of signals from the three different rings.

25 It will be appreciated that the Figure 14 embodiment can be extended to more than three rings. When the number of rings becomes large, multi-color band splitters, all-optical switches, and multi-color combiners are utilized as shown in Figure 12. If each band contains P wavelengths, then the use of multi-band splitters and combiners can significantly reduce the size of the NxN switch or crossconnect (the conventional

approach) by P^2 times. An MxM switch is used because its loss can significantly lower than that of 1xM couplers.

In another embodiment of the present invention, a sufficiently large enough number of wavelengths are shared in at least two rings of large metro ring networks to eliminate O-E-O conversions between the rings. In various embodiments, the number of wavelengths is greater than 300 wavelengths/fiber, greater than 250 wavelengths/fiber and greater than 200 wavelengths/fiber. It will be appreciated that this embodiment can be achieved with a different large number of wavelengths. These embodiments can be implemented, by way of illustration but without limitation, in the large metro ring networks illustrated in Figures 3(a) and 3(b).

In the Figure 3(a) embodiment, booster and pre-amplifiers may not be needed. In Figure 3(a), the main path of the optical ring consists of only passive components. The Figure 3(a) architecture is suitable for a small ring circumference. The Figure 3(b) architecture is suitable for a ring network with a large circumference.

In these embodiments using a very large number of wavelengths, optical couplers are positioned along the main path of the ring network and all wavelength-dependent-OADMs are eliminated. This ring network is a broadcast-and-select optical network which is also referred to as a one-hop network. When optical amplifiers are not used, the number of available wavelengths can be extremely large, especially when the wavelength channel spacing is much smaller than the conventional ITU grid. In this case, however, the network size may be relatively small, because each coupler introduces additional loss.

If optical amplifiers are used, the number of available wavelengths is dependent on the usable bandwidth of the amplifiers. The wider the amplifier gain bandwidth, the more wavelengths are available and no wavelength reuse is necessary. When broadband optical amplifiers are used in combination with ultra-dense WDM technology, as disclosed in U.S. Patent Application No. 09/575,811, dated May 22, 2000, incorporated herein by reference, the number of wavelengths that can be used is very large. It can be desirable to minimize or eliminate the use of active components such as optical amplifiers in order to enable the usage of a large number of wavelengths in a relatively short ring network as disclosed in U.S. Application No. 60/309,220 filed July 31, 2001 which is incorporated herein by reference. In one method of the present invention, the Figure 2(a) ring network acts as a metropolitan passive optical network.

In one embodiment of the present invention, the available number of wavelengths is large enough and are transmitted over a long distance, including but not limited to over 1500 km of conventional single-mode fibers, and can cover multiple interconnected optical networks. In this embodiment, all of the wavelength converters and regenerators between optical networks are eliminated. Additionally, all of the wavelength-dependent OADMs within an optical ring network are also eliminated.

In Figure 3(b), the all optical network has a large circumference, for example greater than 1500 km, and in-line optical amplifiers are added between the add and drop broadband couplers. The in-line optical amplifiers are gain-flattened and gain-equalized. Gain flattened for all wavelengths is used in order to achieve equal gain. Gain flattening is required in order to ensure that when the number of wavelengths on a ring changes, the available amplifier gain for each wavelength remains constant. It is not necessary to place the in-line optical amplifiers at every node in a ring. With this embodiment, the all optical network can be upgraded in capacity and the dynamic wavelength add-drop functionality is made easier because both of these functions can be carried out "off-line" without affecting the main path of the ring. The only limitation is that, due to the limited saturation power of an in-line amplifier, the total number of wavelengths traveling along the ring cannot be more than what an in-line amplifier can handle.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not limited to the disclosed embodiment, but on the contrary it is intended to cover various modifications and equivalent arrangement included within the spirit and scope of the claims which follow.

What is claimed is: